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Optical Instrumentation Support for the
Airborne Ionospheric Observatory

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AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
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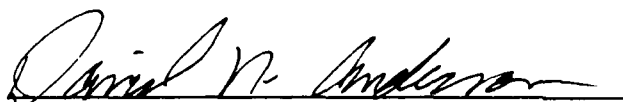"This technical report has been reviewed and is approved for publication"

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This Report summarizes activities during the Contract Year 2, and includes a description of software development for instrument control and calibration, improvements to imaging optics, harware modifications and improvements, mission support on field trips, and data analysis.

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1. Contract Objectives:

To participate in ionospheric research programs using the new optical equipment (designed and constructed by Keo Consultants) that was planned to be installed on the Airborne Ionospheric Observatory (AIO), a research aircraft operated by the Ionospheric Effects Branch at AFGL. This participation to include:

(a) Testing, improvement and continuing development of the software operating systems that control the instrument operation.

(b) Complete testing, calibration and documentation of all optical properties of the optical systems.

(c) Improvements and continuing development of data recording systems for all instruments, and techniques for quick-look data presentation.

(d) Assistance in analysis of optical data obtained on airglow and auroral experiments.

(e) Provide personnel assistance on research flights and field trips as required by AFGL.

2. Changed Contract Objectives during Year I:

The optical equipment involved in this Contract was to be installed on the AIO. The photometers and spectrometers were sent to Wright Patterson AFB for this installation, and the equipment was held there for some nine months and so was unavailable at AFGL for checkout, software development and improvements. Consequently we did not hire a full-time software engineer on this Contract as early as planned, and continued to utilize a part-time engineer to continue development work on the software for the all-sky imaging photometer (ASIP II).

Towards the end of Year 1 it became evident that the optical equipment would probably not be installed permanently on the AIO. Consequently

the emphasis of this Contract changed somewhat to address optimization of the use of ASIP II from the ground in association with various field trips of the Ionospheric Effects Branch, and the facilitation of image analysis. The net result of this change in direction was a decreased level of spending on salaries and an increased level of spending on equipment.

3. Software Development:

(a) Photometers and Spectrometers: These instruments were returned from Wright Patterson AFB, with installation on the AIO being deferred to a later date. Laboratory testing revealed a computer CPU memory limitation problem when running the two spectrophotometers simultaneously with the six photometers. A thorough engineering analysis was undertaken, with detailed recommendations developed for a combination hardware/software solution. These recommendations are discussed and fully documented in the report entitled "Suggested Upgrades for the Photometer/Spectrometer System" and supplied to AFGL. An abstracted version is included here as Appendix I.

(b) ASIP II: Operational software development was essentially completed during Year I. During Year II, software was developed for automatic calibration of ASIP II. The software takes the operator through a complete system calibration with appropriate screen instructions and prompts, with the full procedure taking about 40 minutes. This software was documented in the report entitled "ASIP II - All Sky Imaging Photometer - Calibration Software User's Manual" supplied to AFGL, and included here as Appendix II.

Prior to sending ASIP II on a field expedition to Arecibo, Puerto Rico in March/April, 1988, several minor additions were made to the data acquisition and

control software. These were to correct problems that emerged during a Thule campaign in Feb., 1988, and to upgrade ASIP's ability to keep accurate real (civil) time. This improvement in system time was necessary for the Arecibo experiment where it was important to maintain synchronization with the on/off times of the HF Heater and the start/end times of ASIP exposures. This experiment also required new software to subtract the on/off images and to correct for system vignetting of the original ASIP II optics.. The resultant images showed the capability of detecting airglow enhancements in 5577 OI and 6300 OI emissions of just 5 Rayleighs, with good contrast, and so demonstrated the powerful low-light-level capabilities of the instrument.

(c) Keo began development of a new system to record and process scintillations on VHF/UHF satellite signals. The system will be based on a Zenith Z-248 (IBM clone) computer and will be written in "C" Various commercial software packages in C were purchased to begin this development. Initial specifications of the development environment was completed in April, 1988; coding of the prototype system began in May, with prototype software testing expected to begin in July or August, 1988.

(d) Other Software: Software was written to allow recording of ASIP II images on the new Panasonic optical disc recorder. Image sequences through different filters can be recorded on different parts of the disc, so as to allow continuous playback of image sequences at particular wavelengths.

Keo personnel (Mr. Michael Keane) also worked extensively on the new image analysis system delivered by Northwest Research. A large effort involved initial shakedown problems, understanding the system and its capabilities and limitations, and writing modified and new software for specific image analysis and presentation requirements. This system is now used regularly on a variety of tasks,

and is proving extremely valuable to the various projects of the Ionospheric Effects Branch. Future upgrades have been suggested to reduce analysis time, and to allow compatibility with ASIP I images.

4. ASIP II Calibration:

An exhaustive calibration of ASIP was completed, including absolute calibration, spectral sensitivity, vignetting, flat field, resolution, shutter characteristics, temperature effects, phosphor decay characteristics, and linearity wrt gain and exposure. These results were documented in the report entitled "ASIP II - All Sky Imaging Photometer - Calibration Results" supplied to AFGL, and abstracted here as Appendix III.

5. Optics Development and Improvements:

(a) The new telecentric optics design (replacing the original bi-convex element with two plano-convex elements) was evaluated during the ASIP II calibration procedures. Resolution was considerably improved, especially near the edges of the all-sky field.

(b) The reimaging optics was redesigned, replacing the previous plano-convex + meniscus lens pair with a pair of achromats. This led to further resolution and vignetting improvements, and substantially corrected chromatic aberrations which had previously led to slight focal changes with different filters.

(c) A new filter wheel with capacity for five 3" filters was designed and constructed and delivered to AFGL. The new filter wheel controller utilizes a ROM that selects the shortest route (clockwise or anticlockwise) for changing filters in an arbitrary order.

(d) The lens coupling arrangement to the CCD chamber was modified to allow dry nitrogen flushing. This was necessitated because of window frosting problems in the (cooled) CCD detector housing. This problem first occurred in the humid environment encountered on a field trip to Puerto Rico. It was found on investigation that the CCD chamber was no longer holding a vacuum; discussions with Photometrics Ltd.. suggested that this might not be unusual, and that we could not reasonably expect the chamber vacuum to hold for long periods. Because of the impracticality of taking vacuum equipment to the field, it was decided to implement the dry nitrogen flushing. Tests showed that the CCD minimum temperature was not adversly affected, and when frosting next occurred (again on a field trip to a humid environment, Wake Island), flushing clearing the problem in 20-30 seconds.

(e) A new image intensifier mount was designed and built to allow more convenient installation and removal of the image intensifier. This was found to be desirable during the calibration procedures, and we considered it would be desirable in general.

(f) A new optical design was developed (in cooperation with Dr. S. B. Mende of Lockheed Research Laboratories and the Lockheed Optics Design Group) for a high-resolution all-sky optics assembly. The design is specific to the all-sky primary lens, and so does not allow interchange of primary lenses. However it succeeds in giving very high resolution and freedom from chromatic aberration. Although not implemented to date, and requiring specially ground components, the design is available should a future need arise. (See Appendix IV.)

(g) During ASIP II calibration procedures, advantage was taken of the calibration set-up to carry out an absolute calibration of the AFGL secondary standard light sources. These calibrations were provided to AFGL.

6. Hardware Development:

(a) Controller: A new filter-wheel Controller was designed and constructed for the new 5-position filter wheel (see 5(c) above). The following additional features were incorporated into the Controller chassis:

(i) Filter temperature set and readout.

(ii) CCD temperature readout.

(iii) Image intensifier gain control (manual and computer).

(iv) Image intensifier AGC indication and monitoring capability.

(v) Image intensifier HV circuit continuity indication.

(vi) Manual/remote shutter switch.

(vii) Two auxiliary switches.

Incorporation of all the above functions in the one chassis simplified wiring and resulted in a more compact and professional instrument appearance.

(b) Time Base Corrector (TBC): Various problems arose with recording images from ASIP II (from Photometrics scan converter boards) onto the Panasonic optical disc recorder, in accepting images from the disc recorder into the Northwest Research Image Analysis System, and in using ASIP I images in the Northwest Research Image Analysis System. Analysis indicated that a TBC should correct these formatting problems, so a demonstration of the For-A TBC was arranged at AGFL. It has been decided to go ahead and procure one of these units.

(c) Aircraft Power: A requirement arose for an addition frequency converter (400 Hz to 60 Hz) for the AIO, and a used unit was located and purchased.

(d) Foreign Power: To allow operation of the ASIP II in foreign countries, a power converter (220V/50Hz to 115V/60Hz) was purchased.

7. Documentation:

ASIP II documentation was reviewed and updated, and three complete documentation sets were assembled. Two have been provided to AFGL, and one set is retained at Keo. A listing of the contents of these documentation sets, current as of June, 30, 1988, is included here as Appendix IV.

8. Data Analysis:

Keo personnel (Mr. Steven Weisfeldt and Mr. Michael Keane) continued to work with AFGL scientists as requested to assist in the operation of the Northwest Research Image Analysis System on a number of different projects.[Results from such analyses were presented by Dr. E. Weber at the CEDAR Workshop (Boulder, CO.) and the MIT Workshop in June, 1988.]

9. Mission Support:

Keo personnel participated in the following AFGL field trips during Year 2:

(a) Thule, Greenland (Feb., 1988):

Mr. Michael Keane (software and operations support).

(b) Arecibo, Puerto Rico (March and April, 1988):

Mr. Michael Keane (software and operations support).

Other travel included a trip by the Principal Investigator (Dr. R. H Eather to the CEDAR conference in Boulder, CO. in June, 1988 to attend imaging sessiors, and also to attend a special meeting/demonstration at Ball Aerospace in Boulder on CCD imaging techniques.

10. General Repairs, Maintenance, Procurement:

Keo responded to repair and maintenance requirements as they arose during the year, and appropriate parts and/or equipment were purchased as necessary. A partial list, other than work specifically described in the above sections, includes the following:

. Special calibration/test jigs for optical testing and evaluation.

. Procurement of 3 shipping cases for the ASIP II

. Upgrade of optics for one of the film based imagers.

. Procurement of hardware and software for the new scintillation data system

. Procurement of a Varo image intensifier tube with special (blue sensitive) cathode and special (fast white) output phosphor.

11. Personnel:

The following lists Keo personnel who worked on the Contract during Year 2

Dr. Robert H. Eather - Principal Investigator

Mr. Cyril Lance - Software and Hardware Engineer (part time)

Mr. Michael Keane - Software Engineer (full time from Dec., 1988)

Mr. Steven Weisfeldt - Technician and Data Analyst (part time)

Appendix I

The following is abstracted from the Report entitled "Suggested Upgrades for Photometer/Spectrophotometer System" by Cyril A. Lance (Keo Consultants):
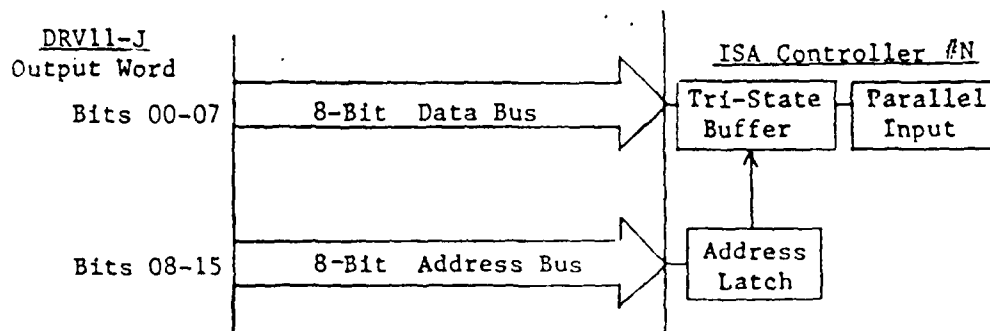
Present Limitations

The major problem with running two Spectrometers right now, is that with all the interupts going on simultaneously and asynchronously, when it comes time to send new commands to the ISA controllers which control the spectrometers, these extra interupts crash the system. Sending commands to one controller at a time is no problem, and that's why we have a working 1 Spectrometer system. But the problem occurs when both ISA controllers decide they need commands at the same time, which will always happen at some point.

With the present software, you could try and trick the controllers into never ending their programs at the same time, but this is a rather silly way of going about things. It seems that the simplest approach to getting a 2-Spectrometer system going is to change the method of communication to the ISA controllers.

At present, the ISA controllers recieve commands through an 5-232 interface. This requires a high-priority interupt at 300 BAUD. My suggestion for the next step in trying to get both spectrometers to run simultaneously, is to change this method of communication to IEEE Parallel interfacing which I believe the ISA controllers already have capability for (A.1). This would be an easy thing to try out, and would get rid of two interupts, and a fair amount of software dealing with sending the information out this way. The only problem is that it would change the cabling to the

ISA controllers (i.e. different origin from computer and more cables going to the controllers Parallel communication could be brought out along the DRV11-J Interface, and thus no cabling needs to be changed there, it would just require cables going from the AZ/EL electronics box to go the the controllers. Hardware could be installed in the ISA controllers to make them addressable. The controllers could then be daisy-chained thus using only one port of the DRV11-J.

```
DRV11-J                                          ISA Controller #N
Output Word

  Bits 00-07 ┌─── 8-Bit  Data Bus ───────▷   ┌──────────┐┌──────────┐
             │                               │Tri-State ││Parallel  │
             │                               │Buffer    ││Input     │
             │                               └──────────┘└──────────┘
             │                                     ▲
             │                                     │
  Bits 08-15 └─── 8-Bit  Address Bus ─────▷   ┌──────────┐
                                             │Address   │
                                             │Latch     │
                                             └──────────┘
```

The software for such an upgrade would be pretty trivial, and would be an easy thing to try out in a stand-alone mode, before implementing in the actual system. Such an upgrade would be an easy thing without much additional hardware to try and get the system operating in a 2-Spectrometer mode.


Reducing Processor Redundancy

At present, the 11/23 computer spends a great deal of it's time during interupts trying to figure out exactly where the ISA controllers are given the total amount of steps sent to the stepper motors. The ISA controllers do a lot of processing to calculate how many pulses to move the stepper motor, the 11/23 counts how many pulses were outputted and then calculates where the ISA controller is. This software is all higher level math, and it takes an extreme amount of time and memory and is a major obstacle in the system design.

This seems like a terribly inefficient means of controlling a system. Since the ISA controller has already done all the mathematical calculations, why bother the 11/23 with such tasks when it is already so over-loaded. The best way of accomplishing such a task from the engineering point of view is to design a system that speaks back to the 11/23 and reports every .1A or so, exactly where it is. The ISA's do, in fact have this capability, but unfortunately, you have to stop the movement before you can read the position.

So, a quick and easy approach to this problem, that would minimize engineering time, and hardware developement cost, is to steal this position information straight from the ISA controller's display board. This is not the best

engineering approach, but as far as cost-efficiency, it might be worth looking into. The display board always displays the current positon during a programmed move (A.2).   Taking this information, and translating it into a 2 word read (8 BCD digits), you could use another DRV11-J port to get the position from the ISA controllers, much in the way that you communicated to the controllers in the parallel method discussed above.
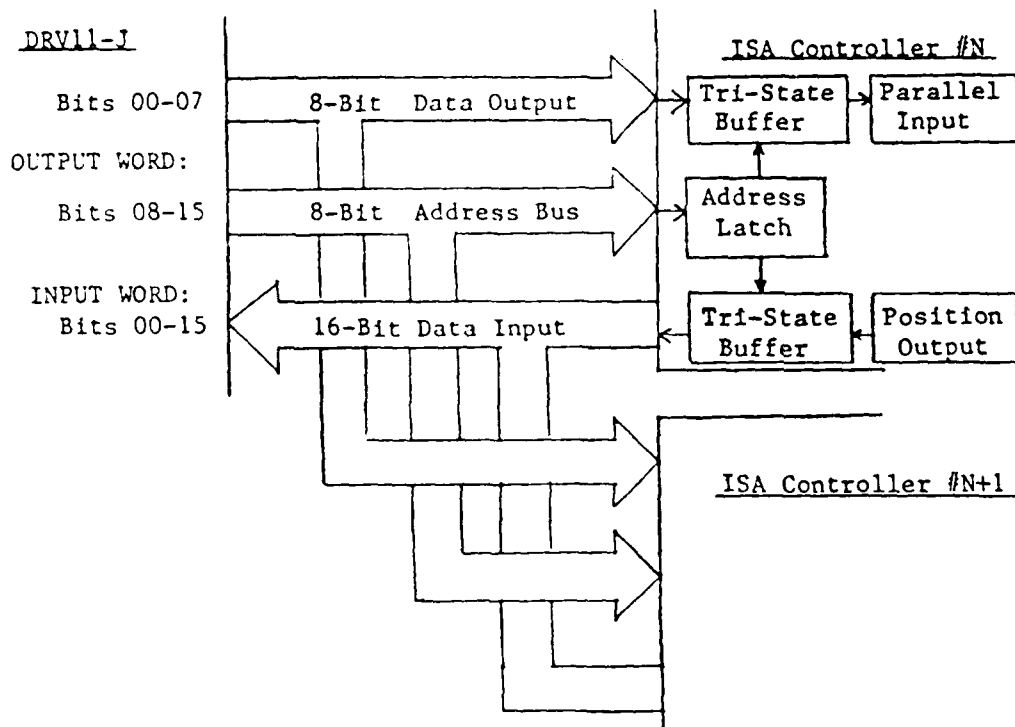
Again, this would require another set of cables interfacing to the ISA controllers from the AZ/EL box and some addressing hardware put into the ISA controllers.   The software would be very trivial and would run extrememly quickly (50-100 usec) much in the same way as the 16-Channel ADC circuit I installed in the AZ/EL electronics in July.

Example ISA Position Read CODE

```
MOV #S1PLRD, @#DROUT     ;Send Contr. #1 Position Low Word
                        ;command to DRV11-J Output Word
MOV @#DRIN, S1POSL       ;Read the Low Word of Contr. #1's
                        ;Position from DRV11-J Input Word
MOV #S1PHRD, @#DROUT     ;Send Contr. #1 Position High Word
                        ;command to DRV11-J Output Word
MOV @#DRIN, S1POSH       ;Read the High Word of Contr. #1's
                        ;Position from DRV11-J Input Word
```

Such an upgrade would free a large amount of CPU time used for the redundant task of keeping track of the Spectrometer positions.   If the above two upgrades were implemented (assuming they worked on a stand-alone basis),
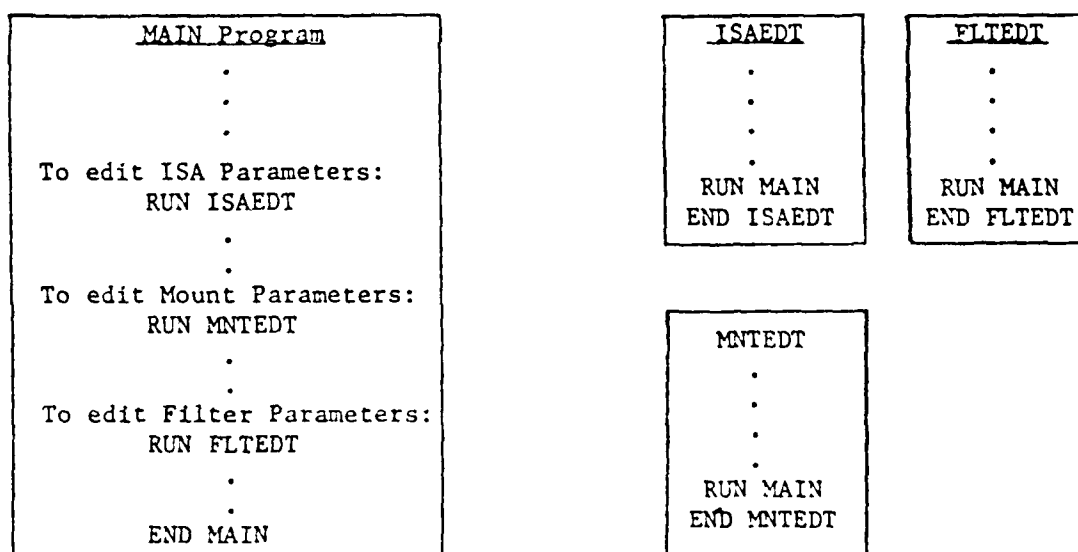
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this would be a quick, easy, cheap method of free the time/space constraints placed on the 11/23 at present.

Reducing Space Constrictions

Another quick and easy fix to some of the computer's problems would be a reduction of program space in the computer's memory. The problem with the 11/23 is that the program can only be a maximum of 26 KWords. You can change the size of memory required without changing the actual software by dividing the programs up into seperate programs that run independently, but connected to each other in a process called CHAINing.

A quick example would be the creation and editing of ISA Controller Command files. While this task is going on, nothing else is happening with the system, so this can be a completely independent program CHAINed to the main program. The main program calls this section into memory, and then this section will call the main program back again when done. There are a number of sections of the program that can be handled this way such as the setting up of the Filter-Tilting and Azimuth/Elevation Control programs. Since these task are always independent, and basically just create a control file, they can run independently.

Example of four Independent CHAINed Programs

```
┌─────────────────────────────┐   ┌──────────────┐ ┌──────────────┐
│        MAIN Program         │   │    ISAEDT    │ │    FLTEDT    │
│            •                │   │      •       │ │      •       │
│            •                │   │      •       │ │      •       │
│            •                │   │      •       │ │      •       │
│                             │   │      •       │ │      •       │
│ To edit ISA Parameters:     │   │   RUN MAIN   │ │   RUN MAIN   │
│     RUN ISAEDT              │   │  END ISAEDT  │ │  END FLTEDT  │
│            •                │   └──────────────┘ └──────────────┘
│            •                │
│ To edit Mount Parameters:   │   ┌──────────────┐
│     RUN MNTEDT              │   │    MNTEDT    │
│            •                │   │      •       │
│            •                │   │      •       │
│ To edit Filter Parameters:  │   │      •       │
│     RUN FLTEDT              │   │      •       │
│            •                │   │   RUN MAIN   │
│            •                │   │  END MNTEDT  │
│         END MAIN            │   └──────────────┘
└─────────────────────────────┘
```

Stand-alone implementation would be an easy thing to check as you could just create independent programs out of the existing code, and use the files they create with the existing controller software. This process of seperating tasks into independent units, would greatly reduce the memory restrictions present in the system, and allow a certain degree of expansion, not permitted with the system, even with the above upgrades.

Total Engineering Approach

It has been suggested that real-time Least-Square-Fits be implemented on the 11/23 so that only one data point need to be stored for each filter tilt cycle. In addition, it has been suggested that the INS data be fed into the computer. These suggestions, and no doubt countless others coming up as experience with the system is gained, point to the fact that what you really want is a data aquisition system.

At present, the 11/23 is used to control mulitple axes, to calculate all the processing information used to control those axes, to process many different levels of interupts, and to read in digital information. This is what makes the 11/23 inadequate for the job.

I feel that a real upgrade of the system could be achieved at many different levels, to relieve the 11/23 of many of it's task and to give the whole system much power. Some of these upgrades would be very easy, and fairly cheap (<$400), and other's would be expensive ($1000-$2000) but would increase the power of your system dramatically. I have done a search of the technology existing today, and feel that there are many options.

My design approach would be to reserve the 11/23 purely for the task of data acquisition and reduction. This would be a very powerful tool on the airplane. Given this simple task, and standardizing I/O in a logical way, the 11/23 could handle many-times the amount of data input that is presently tasked to the machine. (For instance INS, Scintillations, etc. There is already provision for 14 more analogue inputs.) In addition, with the low data rates that the experiments require, and having all information easily accessible, would allow for some limited real-time data analysis, reduction and perhaps even graphic display.

Since the motion of the various axes are very simple, the controllers for these axes don't have to be very intelligent. Each axis would require the following things: A parallel (or RS-232) interface to send commands to it, a little memory to program, some sort of position feedback system and the processor to translate the commands into the actual stepper-motor phase outputs.

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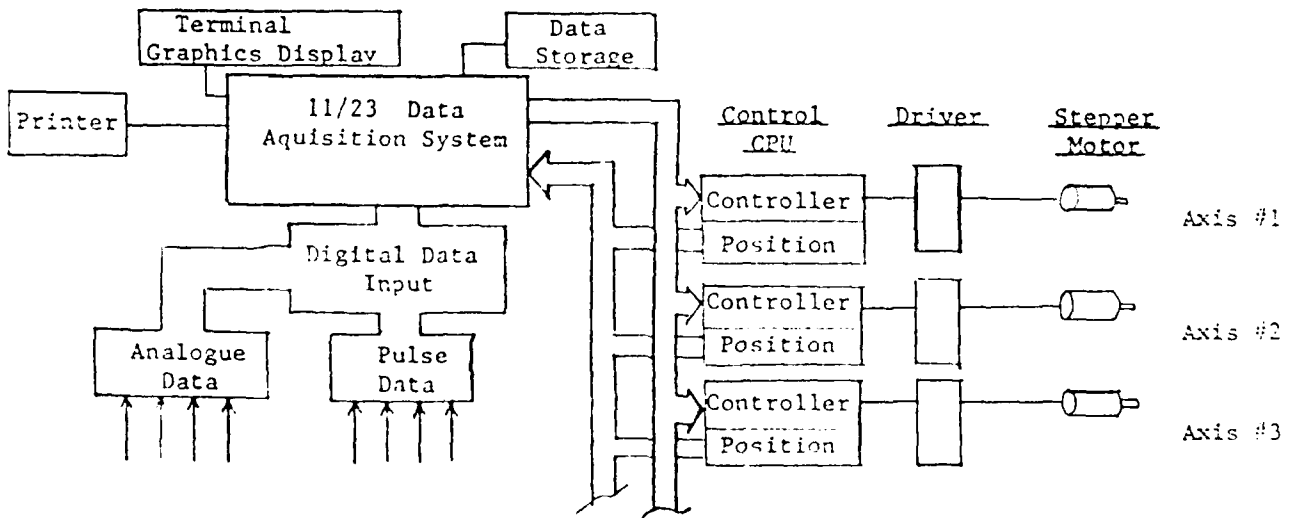
The Spectrometers already have a processor and memory and a RS-232 interface. With the above two modifications, it would have the parallel communication (if needed), and a position feedback system. Thus, the Spectrometers would be all set for this new approach.

The photometers, on the other hand, rely on the 11/23 for all of the above functions. The position feedback is taken care of through the 16-Channel ADC system installed, and the drivers are all set up using the Slo-Syn STM-103 boards. But the programming capability is totally done by the 11/23 right now. The simplest and cheapest approach would be to buy two Cybernetics CY512 Stepper Motor Controller chips (A.3). These chips cost $190 each, and are chips that can be talked to in a parallel mode, be programmed, have limited memory, and can be run totally independently. They can also be coupled together to be started simultaneously.

The advantage of these chips is that they are basically self-contained units. All they would need is an 11 Mhz crystal for $5, and some wiring, and you could test them out in a totally stand-alone environment. Another major advantage from the bureaucratic point of view, is that these chips could easily be installed inside the AZ/EL controller, interfaced straight to the STM-103 drivers being totally invisible to Wright Patterson.
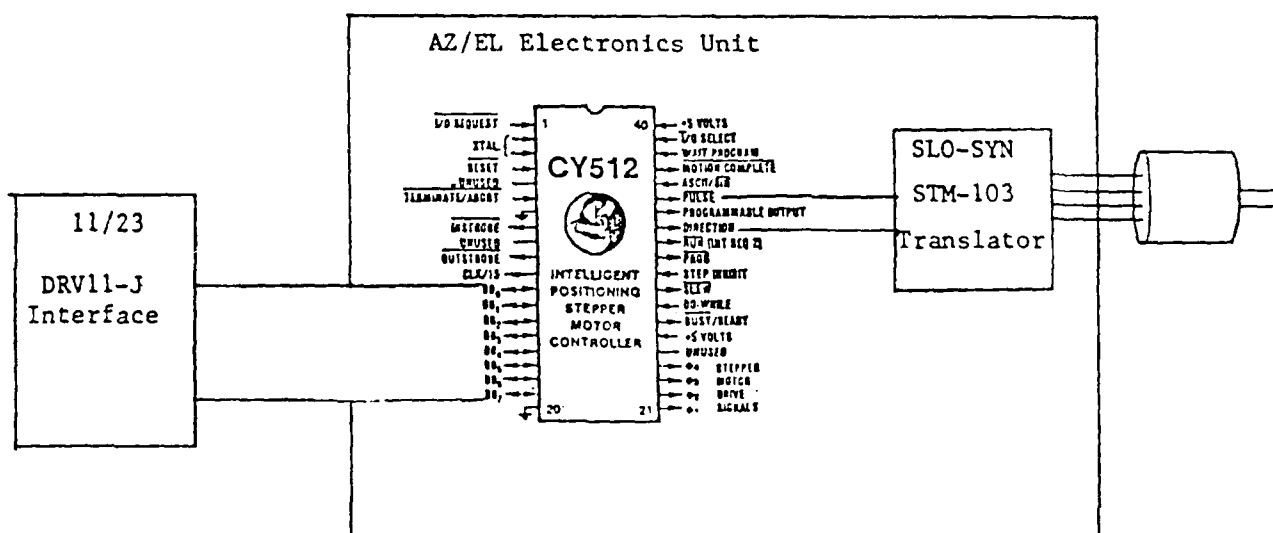
Such a modification, would be fairly cheap, easy to do, and would totally free the computer of any controlling tasks for the axes. Readout could be accomplished in exactly the same method as presently used (i.e. the ADC interface). The CY512 has pretty extensive programming capability, so by eliminating the need for intelligent software in the 11/23, you increase the posibilities for AZ/EL motion control

After such an modification, and the above upgrades in using the ISA controllers, the 11/23 is only tasked with stepping the filter tilting motors. Since this is a straight continuous stream of steps, there is no calculations involved and the software to do this only takes on the order of 10 usecs. The advantage of keeping this interupt under 11/23 control, is that the data acquisition rate is totally coupled to this stepping rate, and thus the interupt to · step the filters, will ·be the same interupt as you data acquisiton interupt. To further ease the software task, the same interupt would be used to acquire the Spectrometer data and you would either store all the information or store only ·every tenth, twentieth, fiftieth... data point.

<u>Example Interupt Routine</u>

```
SAVREG                      ;Save all Registers
MOV #FILSTP, @#DROUT        ;Output Filter Stepper
CLR @#DROUT                 ;Motor Pulses through DRV11-J
UPDPOS                      ;Update Filter Position variables
RDPHOT                      ;Read Photometer Data Input
RDMNTP                      ;Read present Mount position
RDISAP                      ;Read present ISA positions
RDANAL                      ;Read Analogue Data Input
RESREG                      ;Restore all Registers
RTI                         ;Return from Interupt
```

Note: Functions are represented by simplified MACRO's

Now the 11/23 has one interupt at which time all it has to do is to step the filter motors (10usecs), and read each axes (10-20usec/axes). With a maximum stepping rate for the filters of 100Hz, or 1 revolution/sec, and each interupt taking a maximum of 500 usec, the interupts would only take .05 secs/second leaving .95 seconds/second for data analysis, reduction, display, storage, etc. 500usec is a conservative estimate for a system with only 10 axes.

The logical next step would be to use the same chip to control the Spectrometers, only using the driver boards of the ISA controllers to drive the stepper-motors. The problem here is that with 150 Steps/Angstrom and the need to scan ove· 3000 Angstroms at times, you would need to have an absolute step range of around 500,000. Since the CY512 only has a 16 bit Register, the limit is 64 KSteps, thus these chips are not applicable.

However, if you really wanted to go this route and standardize all the axes, . there are several options. Most likely, there are some Q-Bus Multi-Axes Stepper Motor Controller Boards that perform all of the above functions, but I have not been able to find such a board yet. The best option I have so far ·is the Slo-Syn Modulynx System which has a step range of 16,777,215 steps (A.4).

A parallel interface (IOD010) or RS-232 (IOD004) board

can control up to 6 axes simultaneouly through the IOD008
Programmable Indexer board. Each Indexer is about $350, and
there is a Driver Board DRD001 for about $200. Most likely
you would be able to interface the IDD008 to the STM
Translators though, through the PULSE and DIR outputs. The
IOD010 has 4Kx8 of EEPROM with very extensive programming
capabilities but costs $700.
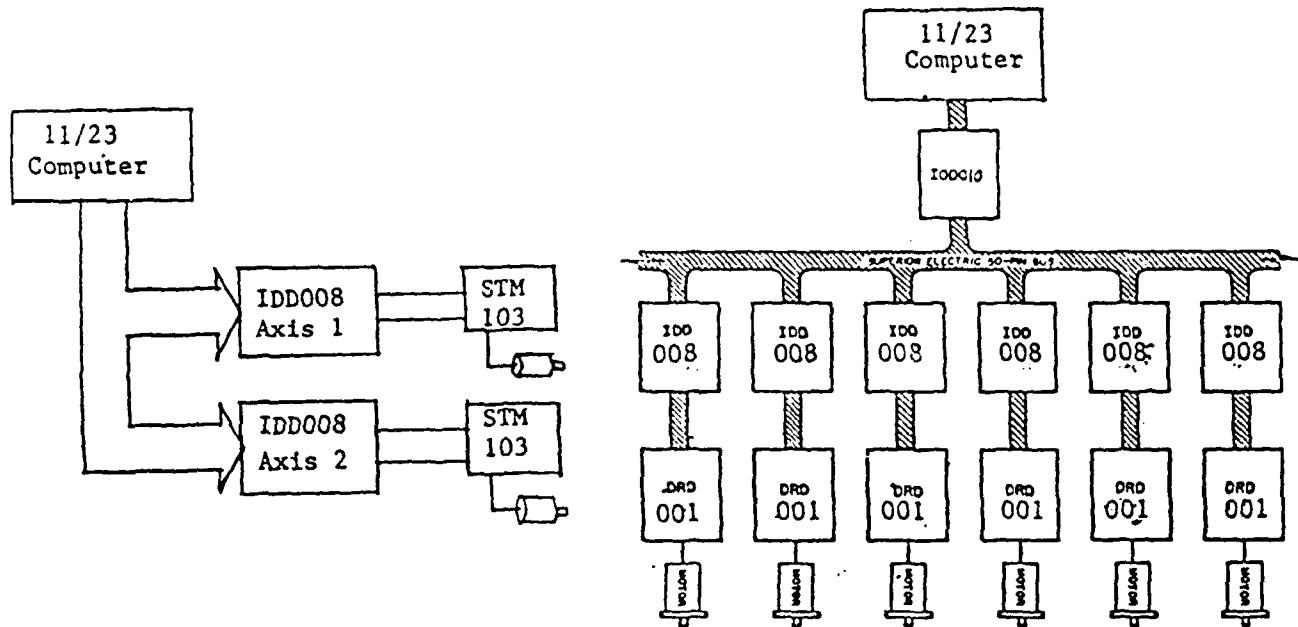
This is a modest approach and there are many more
expensive systems such as the Modulynx system, that I have
researched. The advantage of using this approach is the
standardization of axes, the ease of expansion without
additional engineering, and when you want to add your 2-
Channel Discombobulating Scanning Ferambermeter, all you have
to do, is to buy two boards @ $356/board. Another advantage
is if you want to replace the Spectrometer with the
Ferambermeter, the 11/23 doesn't care, so there doesn't have
to any engineering changes, except perhaps with the
Ferambermeter. (But as instruments go, the Ferambermeter is
pretty straight foward -- unless of course, you're dealing
with a 4-Channel Bicombobulating Multi-plexed Ferambermeter!).

Conclusion

I have outlined a number of options for the
Photometer/Spectrometer System. Software developement for
Least Square Fits, and INS data, etc. weren't discussed, but
anytime you increase your capabilities, there will be a great
deal of engineering time associated with these developements.
What needs to be decided, I think, is how much energy you
want to put into developing this instrument into the most
powerful tool it possibly can be.

It seems that the most straight foward progression

would be:

   (i) Change ISA communication to parallel and see if you
       can get the 2 Spectrometer system to work.

  (ii) Modify ISA Display board to send parallel position
       information to the 11/23 through the DRV11-J.

 (iii) Implement CHAINable software scheme.

  (iv) Buy two CY512 chips and make the AZ/EL mount
       intelligent interfacing to stepper motors through
       the STM Translators.

   (v) With the CPU time and Memory gained from (i)-(iv),
       start developing additional software for analysis,
       reduction, and display.

  (vi) By this time, technology will have progressed even
       further, so devloping an integrated system using
       the general approach discussed in the last section
       will be easier and cheaper. Research best method
       of implementation and re-vamp system. In addition,
       experience gained on the system by this time will
       provide a much clearer picture of what is actually
       needed.

ASIP II

All-Sky Imaging Photometer

Calibration Software User's Manual

December 3, 1987   Keo Consultants

A. General Overview

This manual describes the calibration software written for the All-Sky Imaging Photometer. This software is meant to automate and speed up the calibration procedure and takes about 30-40 minutes for completion.

The calibration procedure uses one of the KEO Integrating Sphere Light Sources and the camera system. To set up for the calibration, the operator must set the light source about 4 inches from the camera. While this is too close to actually have the light source in focus with the fish-eye lens, it is large enough so that you can get good statistics with the software. We have checked to make sure that retroreflections are unimportant by showing the light source give the same signal when located at a farther distance. However, as will be discussed and within the limits of the software provided, you can experiment and set up the calibration any way you like.

Cover this area with black cloth

4"

KEO All-Sky Camera

KEO Integrating Sphere Light Source
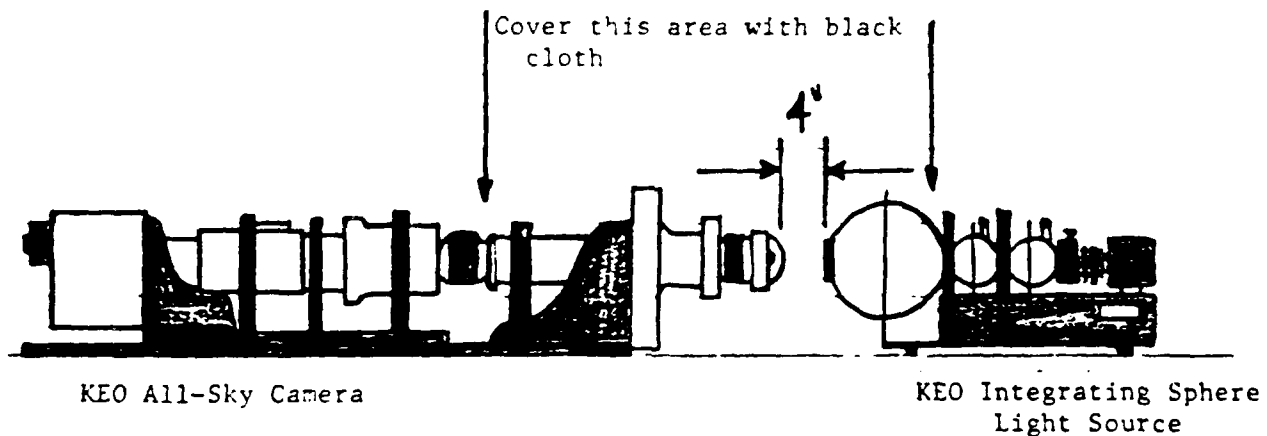
The calibration procedure involves a setup mode, where you take an image using the whole CCD, and determine where the center of the light source lies within the CCD image. You then define your new image to be a square that lies around the center of the light source and well within the edges of the source. This then becomes your new image. The reason for this is that reading a whole CCD image takes a long time. Reducing the image to only the pertinent information (i.e. the light source), you can dramatically cut down the calibration time.

Once your new image is defined, the calibration procedure begins. First a background calibration must be obtained. Setting the light source to the null position, the software runs through 7 different exposures for each of the 4 gains and both prints these values out, and stores them in software. Next the operator sets the light source to the minimum detectable level and the software runs through the 7 exposures for each gain, calculates the mean value of the light source, subtracts the background mean, and prints the value out on the printer.

The operator then sets the light source to a higher level, and the software runs through the procedure again, and on and on up to the maximum light input desired. Note that when the software sees that a longer exposure will saturate the CCD, it will skip the rest of the exposures for that gain setting.

During the calibration the operator has to be careful of a few things. The first and most important is that the calibration system -- that containing the camera system and the light

source – is completely light tight. Black cloth around the camera lens and light source in a darkroom is what KEO used during the initial calibration. When the system is taking the background data, check that the bias and noise signals look reasonable, and increase in a linear way with the exposure and gain parameters.

During the first light source setting calibration, it is a good idea to record the mean values printed out on the screen for every exposure on a piece of paper, and then subtract the background value printed out on the printer and check that the value outputted to the printer for that particular exposure and gain setting agrees with your arithmetic. This checks that the background table is in good shape.

Note that the background table is destroyed every time you reboot the computer, or load the KEO calibration software. So, if you don't do the whole calibration procedure in one setting, you will need to recreate the background data. This is taken care of in the software.

As the calibration software is running, it is good to check that thevalues for the calibration appear to be doing the right things. I.e. when the exposure doubles, the calibration value doubles, or when the gain to the intensifier is halved, the calibration values are halved, etc.

Finally, once all the light settings are completed, the values have to be plotted up against the calibration for the light source supplied by KEO. An example of this would be for a 6 gain 20 obs (1 second) exposure at 6300A, with the light source set at X, you would look up how much light at 6300A the light source gives out at setting X in Rayleighs/Angstrom, and then multiply this by the width of the filter in Angstroms. This value is then divided by the value taken from the calibration printout and gives you N Rayleighs/ADU where ADU is Analogue/Digital Units. From now on, when you take an exposure at 6300A of 6 gain 20 obs, and you get a value of Y ADU's, you multiply Y by N to get an absolute value in Rayleighs for the observed data.

It is important to know that the calibration is specific to each image intensifier, thus you should know which intensifier is in the camera and make note when you change intensifiers (hopefully, not very often). It is probably a good idea to note which intensifier you used on the final calibration graphs.

B. KEO Integrating Sphere Light Sources

The light sources supplied by KEO Consultants have three integrating spheres with the two small spheres having retractable deflectors and an aperture wheel. The final large integrating sphere creates a uniform light source on a 4" diameter diffusing plate at the end of the light source.

A dynamic range of over 10^8 is available from these source by adjusting the aperture wheels and by taking in and out the deflectors in the small integrating spheres. For most calibrations for auroral work with the ASIP, the light sources will only be used with the deflectors down.

Each aperture wheel has 12 settings. An unmarked setting, or null position completely blocks the light from the next integrating stage. Positions 0 through 10 decrease the light source by a factor of two for each setting going from 0 (brightest) to 10 (darkest). Thus each aperature wheel has a dynamic range of 1024.
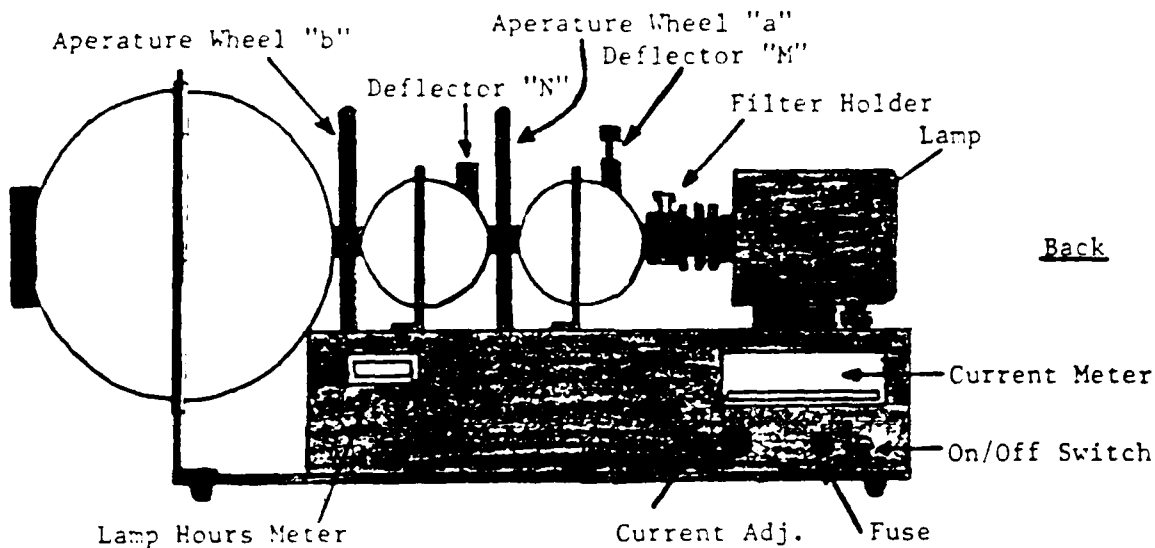
It is important to remain consistent in using these light sources and recording all the settings accurately. Each light source is calibrated at a certain lamp current. You can only use the light sources at the current that it was calibrated at. When you turn the source on, the black vernier knob should be all the way off. As the bulb current steadies, turn the knob clockwise and increase the lamp current until it reaches the value specified in the calibration documentation for the light source. This current will drift significantly during the first 5 minutes of operations, so it is neccessary to let the light source warm up and keep readjusting the lamp current until it stabalizes. Once finished with the light source, turn the lamp current down all the way (counter-clockwise) before turning the source off.

To record the light source setting, a light source nomenclature has been set to make sure that all users are consistent with each other. It is up to the operator to use this nomenclature or develope her/his own, but it is highly recommended to stay consistent. A light source setting is defined as:

$$aMbN$$

where **a** is the aperture setting of the sphere closest to the lamp, and M can be either **u** or **d** depending on whether the deflector is up or down. b and N are similarly defined for the sphere closest to the front of the light source (see figure). Thus, a typical light source setting would be notated as:

Light Source #1 @ 770mA   0d3d

Each light source has been calibrated to a National Bureau of Standards light source and a calibration sheet for all settings is supplied. Comparing this with the calibration results gives an accurate absolute calibration of the All-Sky Camera data in Raylieghs.

C. Using the Computer -- Setting Up

Refer to the ASIPII User's manual for booting the computer and getting into the FORTH system mode. Once at this point, you will need to load the calibration software into the FORTH dictionary as it is not automatically loaded. To do this type:

```
/lf keocal
redef: creac
/
```

The prompt **redef: creac** will appear on the screen and once the / has returned, FORTH is finished and ready for you to continue.

With the light source set on a fairly high setting, such as 0d0d, and the black cloth all set up, clear the CCD and take an exposure and then display this on the screen:

```
/scrub 5 obs show
min: 100    max: 3000
/
```

Reiterate this process adjusting the light source and exposure until you have a good sharp image to work with. Now you are ready to define the new CCD sub-image. Get into the interactive cursor mode (read Photometrics User's Manual under the command **sw**) and determine the edges of a good box. This box must be larger than 32x32 or the Photometrics Software will crash and it will be neccessary to reboot the computer:

```
/sw
```

In this interactive mode, you can move the cross around the image using the keys H,J,K,L and record your position by reading the row and column from the top of the video monitor. Define the four corners of your new image:
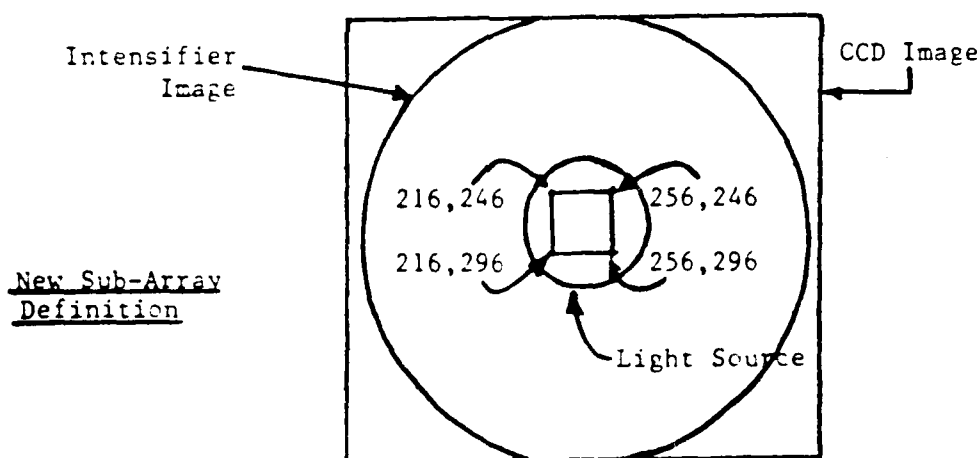
From this define four paramters: col, row, csize, and rsize. For exampl. 246, 216, 50, 40 respectively. Now, you need to redefine the CCD image using the !fmt command:

```
/246 216 50 40 !fmt clcpt
/
```

You are now ready to run the KEO calibration software, but it is a good idea at this point to check this image and make sure it covers the center of the light source and that no edges are included in the image:

```
/gz pz              ( clear the video monitor )
```

/scrub 10 obs sho   (take an exposure and display)

The new image should be just a flat white square. If you can see any parts of the edge of the light source in this image, you must redefine the image:

/default clcpt   (reset the image memory)

and repeat the sw and !fmt procedure.

D. Running the Keo Calibration Software

The KEO software runs automatically as described in the first section. Most of the interaction with the computer is bookkeeping information which is essential for the final absolute calibration into Rayleighs, and serves to guarantee that the operator will not forget any information. To start the software, simply type:

/kcal
Entering Calibration Sequence

Enter Light Source ID: **1**
Enter Light Source Current: **770**
Enter Calibration Wavelength: **6300**
Enter CCD Tempature: **-33.2**
Enter Filter Temperature: **25.4**
Enter Intensifier #: **636201**

Set Printer to top of form ...

The information entered is all pretty self-explanatory. Once entered, and the printer prompt is on the terminal, you should check that your printer is on-line, and that it is at the top of a page. After you are sure it is all set up, you can hit any key on the terminal and the KEO software will resume and start the Background calibration:

Background Calibration

Is Light source turned to Null Position? **y**

The computer will have printed out the calibration sheet header with all the parameter information, and will wait for you to Null the light source. Make sure that both aperture wheels are on the null position (no number) and that the black cloth is set up, and that the room is as dark as possible. Once this background calibration begins, you do not want to touch anything or change the room light situation for the rest of the calibration. Make sure that the CCD has had plenty time to cool down, and that the light source current is rock steady.

After responding with a y, the computer will chug away through the background calibrations, printing out the results on the printer. Check to see that the printer is working properly, and if not, abort the program by typing:

^z

Once the background calibration is completed, the software will go into the light source calibration. The software will cycle through all 7 exposures (1/10, 1/4, 1/2, 1, 2, 4, and 8 seconds) for each of the 4 gain settings and will print out the results:

```
            ASIP Camera Calibration      5OCT87
       Intensifier #: 636201              Filter Temp: 25.40
Light Source: 1  Current: 770  Wavelength: 6300  CCD Temp: -32.4


    Background Calibration      5OCT87  15:13:20

7          136        142        154        178        222        314        504
6          118        121        124        135        157        199        284
5          109        110        113        119        130        153        200
4          104        106        107        110        118        131        156
```

Once the background is finished, the terminal will prompt you to enter the light source setting:

Enter new Light Source position (e.g. 2u3d): 0d3d

Set the light source on the desired setting and enter the light source setting as described in Section B of this manual. The calibration will continue and the printout will continue as:

```
    Light Source Position: 0d3d        5OCT87  15:20:15

7          4          6          12         26         50         101        207
6          2          3          6          10         23         49         94
```

etc., etc....

On the terminal lots of information will be displayed but after the average of 4 images for each exposure has been taken, a statistic line will appear:

    max: 3254   min: 2586   mean: 2785   rms: 25.49

It is the mean from this line that is used for the background arithmatic. You should check this for the fist few values to make sure that the software is working correctly. For example, in the above printout, for a gain of 7, and an exposure of 1 second (first line 4th column), the background was 178. If when this exposure sequence (4 exposures of 1 second averaged together to get better statistics) is finished, and the statistics line gives a mean of 204, then the value printed out should be 26 in the first line, 4th column of the calibration section. In the above example, the results are consistent so that you can assume that the software is working correctly.

It is a good idea to check this carefully for the first light source setting, and after that, you can have a good degree of confidence in the calibration. When you are done with all the light source positions needed for the calibration, you can just type a ^z to get out of the software. The resultant printout contains all the information foran absolute calibration for your camera.

E. Adjusting Calibration Software Parameters

For the more energetic and FORTH enthusiasts, it is very easy to change some of the important Calibration variables by editing the Software in the file keocal located in directory

camera. This is not recommended for anyone who is not familiar with the FORTH editor or who has not had experience with FORTH programming.

The important variables used in the calibration software are stored in four orphaned variables defined in the first block of code in line 3.

    0 wvariable caltbl 56 allot   0 int6 0 int7 0 int8 0 int9

The variable caltbl is the beginning of the table that stores the background information.   Variable int6 stores the pointer to where the software is in the table. Variable int7 stores the number of repetitions used for the image averaging. Variable int8 stores the pointer which points to values in the exposure table exposu in block 3. Variable int9 store the exposure time during the calibration sequences. These are not normal FORTH variables but rather 'orphaned' variables as defined in the utilities file.

The two things that operators could possibly want to change would be the value of int7 or the number of repetitions and the actual exposures stored in the exposure table exposu.

Changing the exposures is very straight forward. All one would have to do is to change the the values stored in exposu by editing line 8 of block 3. The exposure units are in Photometrics units of 50 msecs, and 2 is the minimum, due to shutter limitations.

The repitition number was set to four so that the calibration procedure would not take too long. The more repetitions, the better the statistics and thus the more accurate the calibration. Let's say we wanted to change the repetition number to 10. We would have to edit the following lines:

    In line 7 of block 4:

        10 str7 caltbl str6 4 0 DO lp cr

where the bold print (10) is the variable that needed to be changed.

    In line 1 of block 4:

        : gacal callbl 10 str7 caltbl str6 4 0 DO

Editing these two lines would give you a calibration procedure that lasted longer but gave you much better statistics. Since the calibration is done so rarely, it might be worth extending this parameter.

Other modifications will no doubt come to mind as you become familiar with the software. As in any FORTH application, be our guest -- just back up your work!

The following is abstracted from the Report entitled "ASIP II - All Sky Imaging Photometer - Calibration Results" by Robert H. Eather and Cyril A. Lance (Keo Consultants):

ASIP II Calibration Results

This report will discuss work done by KEO Consultants on the All-Sky Imaging Photometer between September and December of 1987 to align and calibrate the camera in it's new camera mount. All the work discussed here is supported in de.·th in the Calibration Log Book kept at KEO Consultants and results will refer to page numbers in this book. Extensive work was done during this period to understand all components of the ASIP, and both the camera mount and the optics were re-vamped including upgraded telecentric optics and a complete Mamiya lens set for the imager to enable the instrument to operate at different field of views. This report will not go into the details of all these studies, but will just summarize the important results.

A. Resolution

All components of the Imager were focused carefully and resolutions of the different components were measured. The relay lens coupling the image intensifier was focused using a lens colimator and scribe marks were added to mark the correct position of this lens. The CCD relay lens was focused using the a standard TV test pattern projected through an ORIEL light source down onto the CCD. Using this test pattern the line resolution of the image intensifier was found to be 30 line-pairs/mm (lp/mm). (Page 1)

At 1x1 binning, we calculated the CCD resolution to be 20 lp/mm. (Page 2) In practice though, one needs to know how well the CCD can resolve a pattern of black and white lines. Using the Air Force Test Pattern, we measured the Modulation Transfer Function (MTF). (Page 5) For an MTF of 20%, we found a resolution of 7 lp/mm.

The ability to resolve two point sources next to each other was measured (Page 114) noting the limitations for not having the point sources at infinity and hence not exactly in focus. It was found that we could just resolve the sources with a .66 degree separation which corresponds to 2 pixels/line-pair at the CCD.

B. Vignetting

Vignetting for the whole camera system was measured (Page 118) and the results were plotted . (Figure 1) Vignetting was also measured at the fastest shutter speed to demonstrate vignetting due to the shutter's physical limitations at very short exposures. However, since most of our exposures are on the order of a second or more, this is not really a problem.

C. Shutter Limitations

Because we had encountered problems with the shutter not opening correctly, much effort was put into understanding the shutter. As mentioned in the previous section, vignetting due to the speed of the shutter opening and closing can affect the overall image and the system sensitivity. It was found that the Photometrics shutter circuit was not supplying enough currrent to reliably open the shutter, so the circuit capacitance was increased and this cleared the problem. A minimum of 1/4 second should always be maintained between successive exposures to guarantee proper shutter operation. The physical dynamics of the shutter were measured and it was found that the opening time for the shutter is 20 msec, and the closing time is 30 msec. (Pages 31-33)

D. Field of View -- Optical and Video

The field-of-view of the system was measured with the Mamiya fish-eye lens and was found to be 180 degrees. However, it was also found that the Photometrics scan converters do not display the full CCD image due to the limitations of video format ratios. With a normal display, the scan converter only displays columns 16 to 495 (rows 0 to 511). Thus, to look at the full CCD image (and thus the full field-of-view) one must either pan the image or squeeze it when displaying it on the Photometrics system.

E. VARO Image Intensifiers

Transient and thermal properties of the VARO intensifiers were studied in depth. Transient rise times of the three phosphors used on our intensifier (Red, Blue, and Green) were found to be about .25 seconds at both +22C and -12C.

Decay times were found to be about twice as long at -12C as they were at +22C. 10% decay times were found to be 16 msec at +22C and 25 msec at -12C, and 1% decay times were found to be 200 msec at +22C and 300-400 msec at -12C. (Pages 63-70) These values are of interest to us because the thermal noise of the image intensifiers decreases with temperature. Some camera designs cool both the CCD and the intensifier to around -35 degrees Centigrade (where the decay time would be much longer). In this case, image retention becomes a problem. This study has led to a KEO design of a cooler that cools only the intensifier cathode and keeps the phosphor at room temperature, thus decreasing the thermal noise of the cathode and retaining the quick decay times of the phosphor necessary for sequential exposures.

During these studies, it was found that there is a sensitivity rise time associated with turning on the image intensifier for the first 45 seconds. This is not a problem for our normal operation, since the intensifier is always left on, but should be noted for use in strobed situations. (Pages 78-83)

Image retention was measured on the CCD from the image intensifier and it was found that after a 45 second intense exposure less than 1% of the original signal is left after 1/4 second at room temperature. (Pages 93-96)

F. Spectral Calibration

A spectral calibration of the system was made by spectrally calibrating the light source with a spectrometer and then calibrating the ASIP system. The results are summarized in Figure 2.

G. System Calibration

Finally, using the KEO calibrated light sources, we fully calibrated the ASIP system at the four intensifier gains and for 7 different exposures. Calibration software was written to automate this procedure for the future (see KEO Consultants report Calibration Software User's Manual). The camera was calibrated at 6300A, and a set of normalizing factors were calculated using the measured filter transmission characteristics and the system spectral sensitivity

relative to 6300A (see Plot 2). (Pages 133 -137) . An example of these calibration curves is shown here as Figure 3.
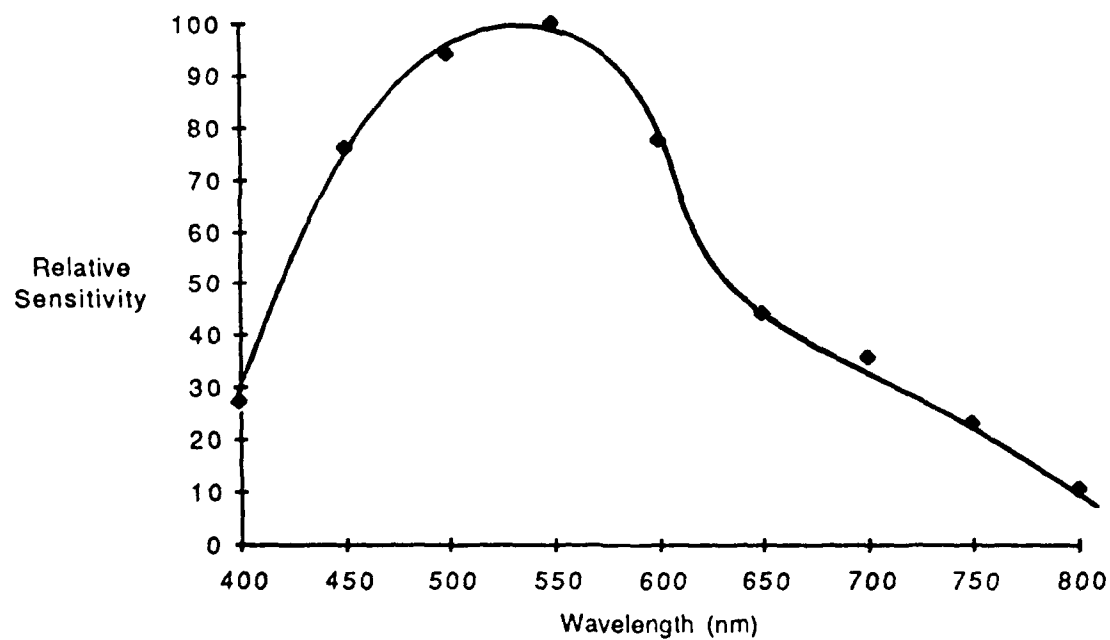
Plot 1

System Vignetting

Relative Intensity

Degrees from Zenith

Plot 2

System Spectral Sensitivity

Relative Sensitivity

Wavelength (nm)
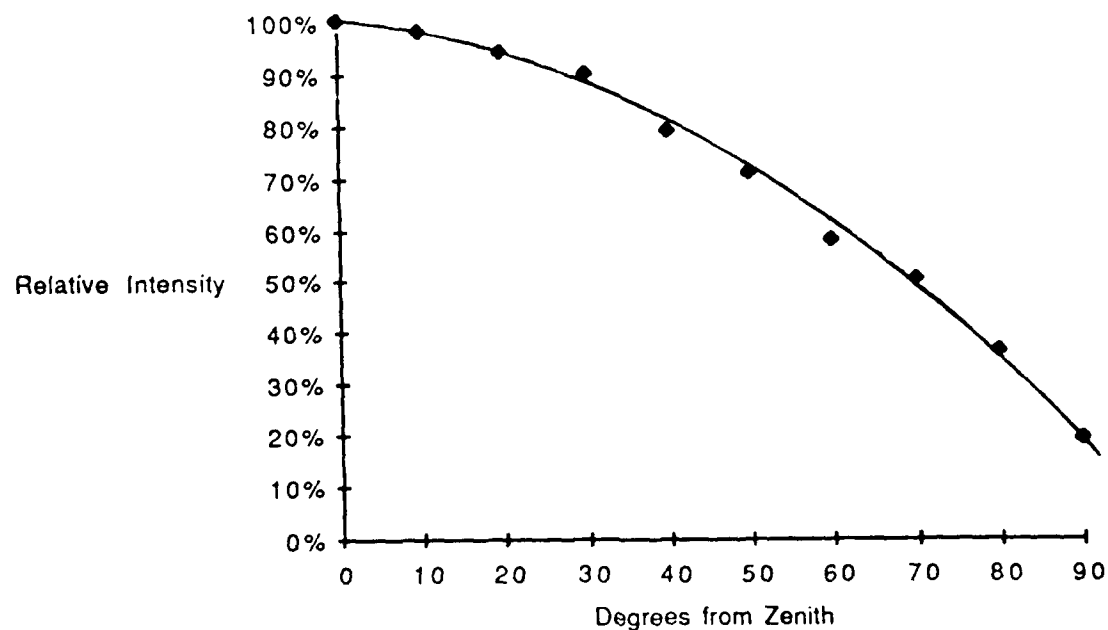
Appendix IV

KEO Documentation Inventory

A. Manila Folders

AOS	Spectrometer
AOS	Filter Chamber
AOS	AZ/EL Controller
AOS	Photon Counting Interface/Ratemeters
AOS	Lambda Multi-Power Supply
AOS	Amplifier/Discriminators
AOS	Photomultiplier Tubes
AOS	PM Tube Coolers
AOS	Temperature Controllers
AOS	Junction Boxes
AOS	Cables
AOS	HV Power Supply
ASIPII	Photometrics Camera -- General
ASIPII	Filter Wheel/Image Int./Shutter/Relay Lens/CCD
ASIPII	TV monitors and Video Switcher

B. Manuals

AOS/ASIP	Kennedy 9000 Tape Drive -- Oper. & Maint. Manual
AOS/ASIP	Kennedy 9000 Tape Drive -- Appl. & Inter. Guide
AOS/ASIP	Kenney 9200 Embedded Formatter
AOS	Western Peripheral TC-151 Tape Contr. Hardware Man
AOS	Western Peripheral TC-151 Tape Contr. Logic Manual
AOS	Western Peripheral TC-151 Tape Contr. Diaganostics
AOS	CODAR 140 M-Timer Board User's Manual
AOS	Am9519A Universal Int. Controller Technical Manual
AOS	Am9513A/9513 System Timing Controller Tech. Manual
AOS	VT-100 User's Guide
AOS	ISA u-Processor Spectrometer Controller Manual
AOS	DSD 880x/30 Floppy and Wincheseter User's Guide
ASIPII	Photometrics DIPS User's Manual
ASIPII	Photometrics 183S/CC180A CCD Camera User's Manual
ASIPII	Photometrics FORTH User's Manual 85.08 (outdated)
ASIPII	IoFORTH Manual

ASIPII	IoFORTH Dictionary
ASIPII	Heurikon HK68/M10 User's Manual
ASIPII	Heurikon FDIO SBX Expansion Interface User's Man.
ASIPII	Heurikon MLZ-814 Enclosure User's Manual
ASIPII	Heurikon Hbug User's Manual
ASIPII	Heurikon HK68 Schematics
ASIPII	Heurikon HK68 Appendices to User's Manual
ASIPII	Zendex ZBX-288 SCSI/CLOCK/CAL Expansion Board
ASIPII	Maxtor XT-1000 Winchester Prod. Specs and OEM Man.
ASIPII	Mistubishi M2896-63 8" Floppy Disk User's Manual
ASIPII	Adaptec ACB-4000 5 1/4" Winch. Contrl. User's Man.
ASIPII	Omnibyte OB68K/Int.(P) Paral. Interface Board Man.
ASIPII	u-Memory MM9000D Memory Board User's Guide
ASIPII	Io SCSI902 9-track SCSI Controller User's Manual
ASIPII	u-Term ERGO 301 Terminal User's Manual
ASIPII	u-Term EROG301 ReGis Graphics Reference Guide